The Flash Flood Potential Index at WFO Des Moines, Iowa

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Acknowledgments

The authors would like to thank the many people who made this document possible. First, NWS members involved in earlier iterations of the Flash Flood Potential Index shared suggestions and experiences which helped this project move forward at WFO Des Moines. In addition, valuable suggestions and questions were provided by many members of the NWS, the media and officials at various levels in the private and public sectors. Their contributions have helped to make this tool even more valuable and thus are greatly appreciated.

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1. Overview

1.a. The Need for the FFPI

Flash flooding is the top weather-related killer, responsible for an average of 140 deaths per year across the United States. Although precipitation forecasting and understanding of flash flood causes have improved in recent years, there are still many unknown factors that play into flash flooding. Despite having accurate and timely rainfall reports, some river basins simply do not respond to rainfall as meteorologists might expect. The Flash Flood Potential Index (FFPI) was developed in order to gain insight into these "problem basins", giving National Weather Service (NWS) meteorologists insight into the intrinsic properties of a river basin and the potential for swift and copious rainfall runoff.

1.b. Goal of the FFPI

The goal of the FFPI is to quantitatively describe a given sub-basin's risk of flash flooding based on its inherent, static characteristics such as slope, land cover, land use and soil type/texture. It leverages both Geographic Information Systems (GIS) as well as datasets from various sources. By indexing a given sub-basin's risk of flash flooding, the FFPI allows the user to see which sub-basins are more predisposed to flash flooding than others. Thus, the FFPI can be added to the situational awareness tools which can be used to help assess flash flood risk.

1.c. FFPI Disclaimers

Note that the FFPI is only a tool. It is not a panacea. Like other tools, the FFPI has its own limitations. For example, the FFPI does not consider real-time soil moisture values which can vary on small time scales. Although soil moisture is admittedly an important consideration in assessing flash flood risk, the FFPI does not consider it in order to be simpler. To consider soil moisture, the FFPI would have to incorporate real-time modeling. Without the soil moisture consideration, the FFPI can be a static information source. In addition, by leaving out soil moisture the FFPI is a good "background information" data source.

2. History of the FFPI

2.a. Colorado Basin River Forecast Center

The FFPI was developed by Greg Smith and others at the Colorado Basin River Forecast Center (CBRFC) (Smith 2003). Its purpose was to supplement conventional tools such as the Flash

Flood Monitoring and Prediction System (FFMP). FFMP is used operationally at WFOs. One of its major inputs is flash flood guidance (FFG).

According to Smith, the application of conventional FFG in CBRFC's service area had serious limitations due mainly to the following reasons (Smith 2003):

1. Scale limitations associated with the datasets used in calculating FFG. The input data were far coarser than the spatial and temporal scales upon which flash floods occurred.
2. Scale limitations associated with the model used in calculating FFG. At CBRFC, the Sacramento Soil Moisture Accounting (SAC-SMA) model was used to calculate FFG. The SAC-SMA model is a lumped model which—by definition—uses parameters and variables that are averaged over an entire sub-basin. In many cases, the geographic size of the SAC-SMA sub-basins far exceeded the geographic size of the catchments within which flash flooding may occur.
3. Calibration limitations associated with the model used in calculating FFG. The SAC-SMA model must be calibrated for each sub-basin using a sufficiently long time series of hydrologic data. For CBRFC, the needed data was typically available only for gaged sites which represented watersheds up to several hundred square miles in geographic size. Again, such size scales far exceeded the geographic size of basins within which flash flooding may occur.

Thus, there was a need to accurately assess the flash flood risk of small basins—ideally for those basins used in FFMP. Such basins were much smaller than the basins used in the SAC-SMA model and are typically based upon which flash floods occur. CBRFC developed the FFPI in response to this need. According to Smith 2003:

> The concept [involved in developing the FFPI] is fairly simple. The process involved acquiring or developing raster (gridded) datasets that represent the type of physiographic characteristics that influence the hydrologic response and flash flood potential. These datasets were then geo-registered and re-sampled to a consistent resolution using a bilinear or nearest neighbor method. A relative flash flood potential index ranging from 1 to 10 was assigned to each data layer based on the layer attributes associated with the hydrologic response. For the initial analysis a simple equal interval classification scheme was used. These values simply represent a grid cell's susceptibility to flash flooding relative to neighboring cells. The values are unit-less.

This index was created utilizing GIS mapping software to overlay four physical elements that relate to precipitation runoff. These properties are: slope of the terrain, land cover/use, soil type/texture and vegetation cover/forest density. These elements were each scaled to create an overall indexed value that forecasters could use to locate basins that may respond more quickly than expected. An index value of 1 indicates a minimum flash flood threat and an index of 10 indicates a maximum flash flood threat.

The datasets that Smith used are listed below. Refer to Smith 2003 for more information on these datasets.

- **Slope:** U.S. Geological Survey (USGS) Digital Elevation Model (DEM).
- **Land Cover/Use:** Early 1990s Land Remote Sensing Satellite (LANDSAT) Thematic Mapper data purchased from the Multi-Resolution Land Characterization (MRLC) Consortium.
- **Soil Type/Texture:** State Soil Geographic (STATSGO) soils data compiled by the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). Data from the LANDSAT images were used where detailed STATSGO maps were not available.
- **Vegetation Cover/Forest Density:** Provided by the USDA, Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis (SO-FIA). The USDA/SO-FIA generated the dataset by using NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data.

The indexed values for each of the above layers were averaged together to generate a composite index value grid of flash flood potential. The slope layer was weighted slightly more than the others due to significant impact that the slope has in flash flood development in CBRFC's service area. Thus,

$$FFPI = \frac{(\,M + L + S + V\,)}{N}$$

where

M = Slope

L = Land Cover/Use

S = Soil Type/Texture

V = Vegetation Cover/Forest Density

N = Sum of weightings. (L, S and V are given weights of 1. N is slightly greater than 4 since M was given a weight of slightly more than 1.)

Equation 1. FFPI equation developed by Smith (2003).

Figure 1 shows the final FFPI map for the CBRFC service area.

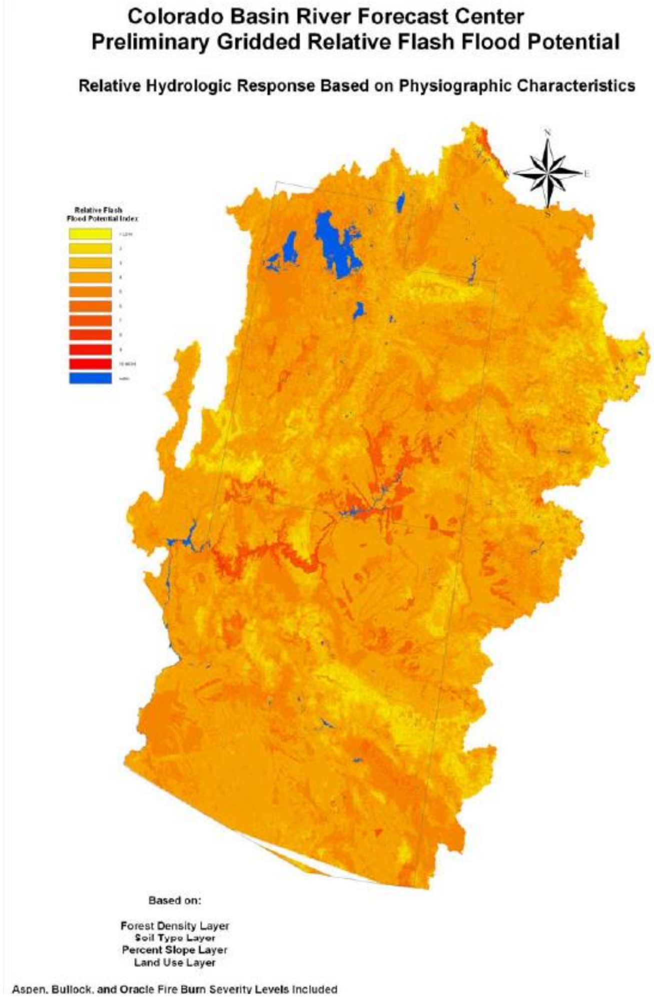


Figure 1. FFPI map for CBRFC service area. Source: Smith 2003.

2.b. WFO Binghamton, New York

James Brewster implemented the FFPI for WFO Binghamton in 2009. He modified the FFPI from Smith's original version for use at WFO Binghamton. The key modifications from Smith's original version were:

- **Slope Index**. Indexed any slopes of 30% or greater as 10.
- **Element Weightings**. Slope was given a weight of 1.5 and Vegetation Cover/Forest

Density was given a weight of 0.5.

Thus, the FFPI equation that Brewster used was:

$$FFPI = \frac{(\,1.5(M) + L + S + 0.5(V)\,)}{4}$$

Equation 2. FFPI equation developed by Brewster (2009).

Figure 2 shows the FFPI grid map for the WFO Binghamton service area. Figure 3 shows the FFPI map for the same area, but zonally averaged to FFMP sub-basins. For more information refer to Brewster 2009.

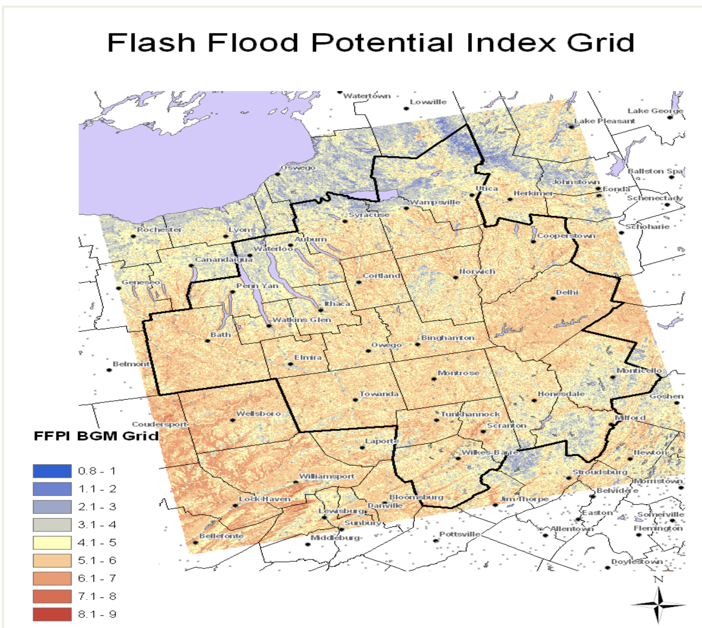


Figure 2. FFPI grid map for the WFO Binghamton service area. Source: Brewster 2009.

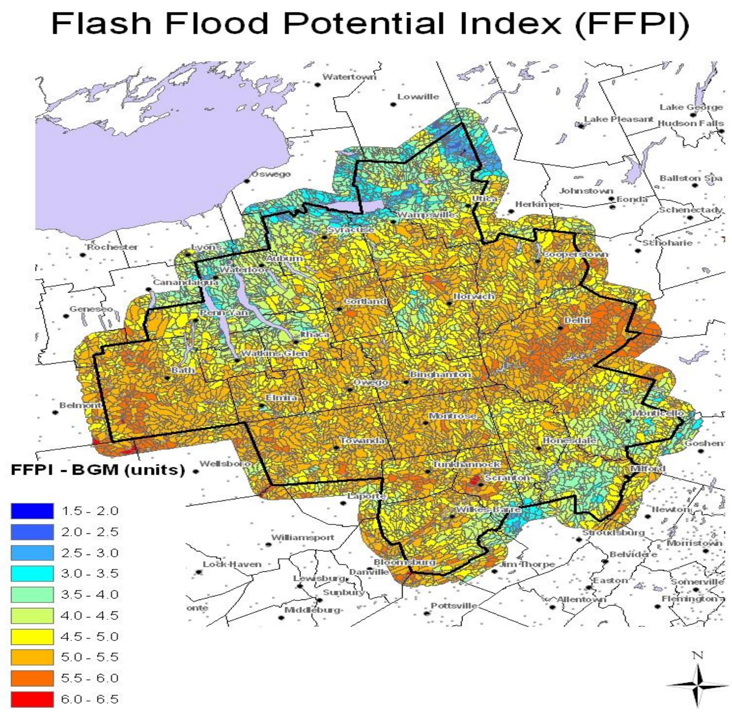


Figure 3. FFPI map for WFO Binghamton service area, zonally averaged by FFMP sub-basins. Source: Brewster 2009.

2.c. WFO Mount Holly, New Jersey

Raymond Kruzdlo and Joseph Ceru implemented the FFPI at WFO State College, Pennsylvania in 2010. Kruzdlo modified the FFPI from Smith's original version for use at WFO State College. The key modification was that all elements were given equal weighting.

Thus, the FFPI equation that Kruzdlo used was:

$$FFPI = \frac{(M + L + S + V)}{4}$$

Equation 3. FFPI equation developed by Kruzdlo (2010).

Figure 4 shows the FFPI grid map for the WFO Mt. Holly service area. Figure 5 shows the FFMP map for the same area, but zonally averaged to FFMP sub-basins. For more information refer to Kruzdlo 2010.

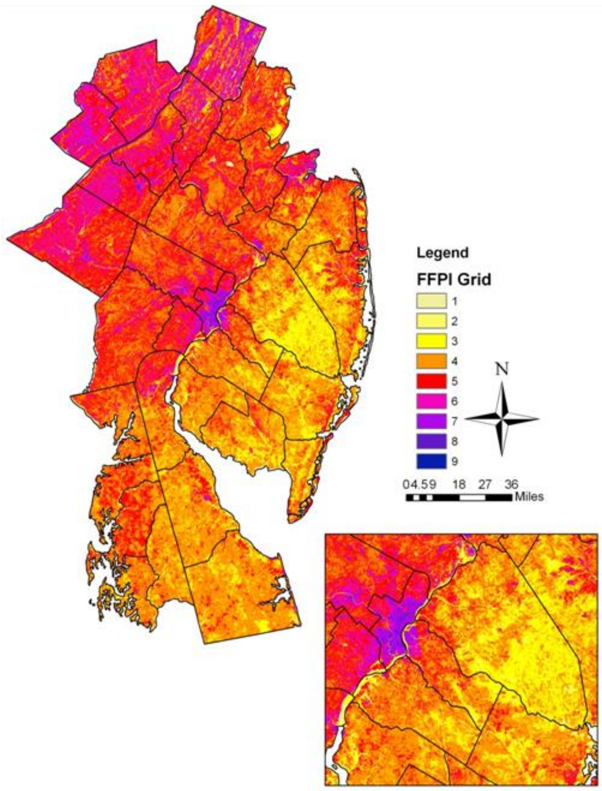


Figure 4. FFPI grid map for WFO Mt. Holly service area. The inset map shows the Philadelphia area. Source: Kruzdlo 2010.

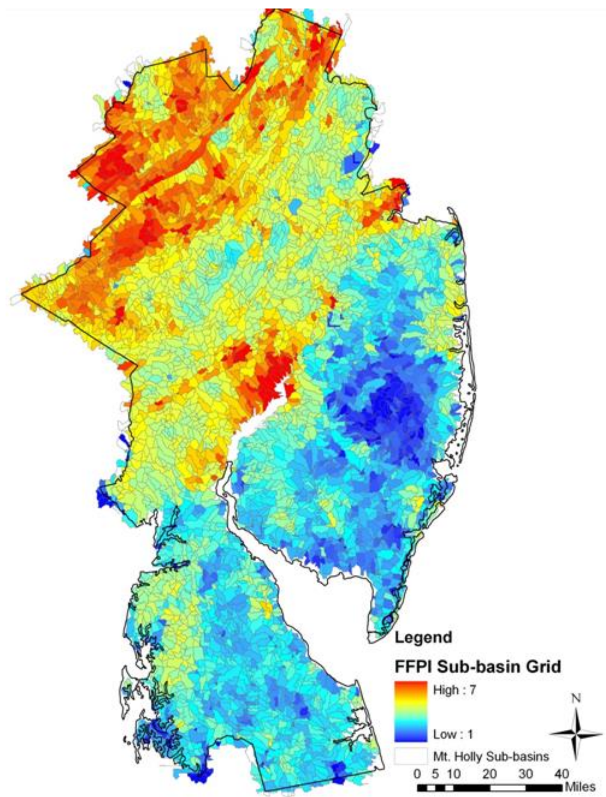


Figure 5. FFPI map for WFO Mt. Holly service area, zonally averaged by FFMP sub-basins. Source: Kruzdlo 2010.

2.d. WFO State College, Pennsylvania

Joseph Ceru implemented the FFPI at WFO State College, Pennsylvania in 2012. Ceru modified the FFPI from Smith's original version for use at WFO State College. The key modification was that extra weighting was given to Slope as well as Land Cover/Use.

Thus, the FFPI equation that Ceru used was:

$$FFPI = \frac{(\,M + L + S + V\,)}{N}$$

where

N is greater than 4 since M and L were each given weights of greater than 1.

Equation 4. FFPI equation developed by Ceru (2012).

Figure 6 shows the FFPI grid map for the state of Pennsylvania. Figure 7 shows the FFPI map for the same area, but zonally averaged to FFMP sub-basins. For more information refer to Ceru 2012.

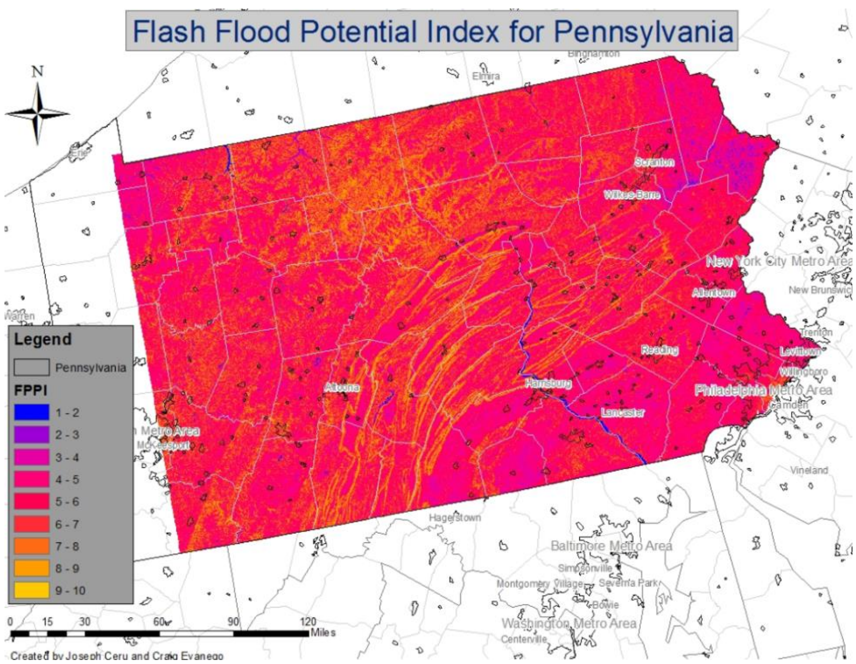


Figure 6. FFPI grid map for the state of Pennsylvania. Source: Ceru 2012.

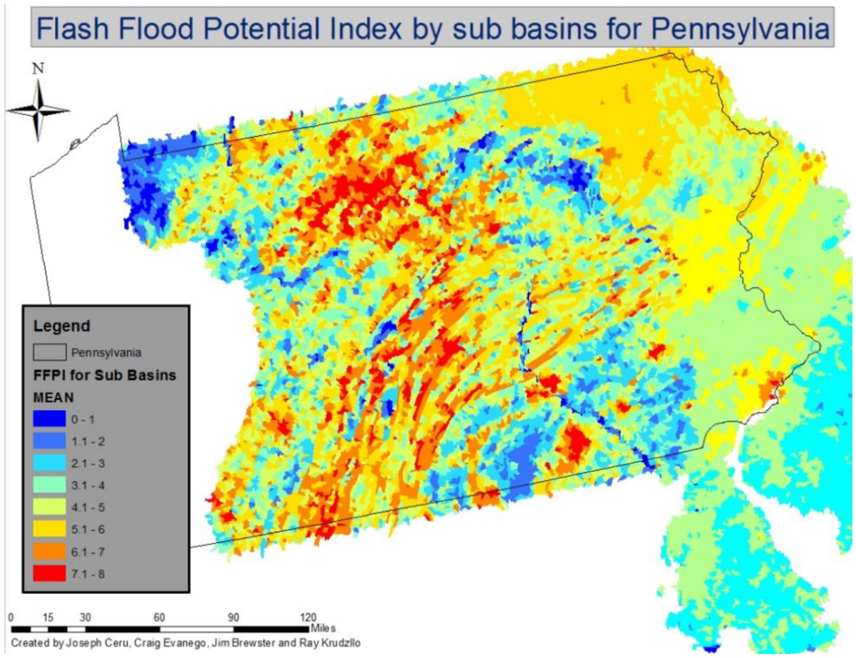


Figure 7. FFPI map for the state of Pennsylvania, zonally averaged by FFMP sub-basins. Source: Ceru 2012.

3. Data Used at WFO Des Moines

The datasets that were utilized in this extensive project encompassed several government agencies and came packaged in various methods.

3.a. Data Selection Criteria

The following criteria were used in selecting the datasets:

- **GIS-compatible format.** The data should be in a format that would allow for analysis and processing by GIS software. For WFO Des Moines, ESRI shapefile or raster GRID format would work best.
- **High resolution.** The data should be sensitive to changes in the actual conditions over relatively small geographic scales.
- **Current or recent data.** For conditions such as land use that may change over time, the data should be relatively current.
- **Seamless data.** The data should not have any artificial discontinuities especially along political or otherwise non-natural boundaries. Artificial discontinuities may negatively

impact the FFPI calculations and results.

- **National coverage and availability.** The data should be available for the geographic domain of the entire United States or at least of the CONUS. This availability will help facilitate a reproducible approach and procedure for additional studies and implementations involving the FFPI.

3.b. Datasets Obtained

Datasets were used at WFO Des Moines for the below categories. For purposes of this project, the data was collected for the state of Iowa as well as regions of adjacent states.

3.b.1. Slope

The National Elevation Dataset (NED) was used. It is the primary elevation data product of the USGS. The NED is a seamless dataset with data available for the conterminous United States, Alaska, Hawaii and territorial islands. NED data are distributed in geographic coordinates in units of decimal degrees and are inherent with the North American Datum of 1983 (NAD83). All elevation values are in meters. The NED data used for this project was downloaded at 1 arc-second resolution or about 30 meters.

The actual downloaded data was elevation data. The ArcMap Spatial Analyst extension was used to calculate the slope.

Below are Web sites where NED information and downloads are located.

- NED information Web site: http://ned.usgs.gov/ .
- NED data download Web site: http://seamless.usgs.gov/ .

3.b.2. Land Cover/Use and Vegetation Cover/Forest Density

The USGS Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) dataset was used. It depicts the Nation's major ecosystems, wildlife habitat, vegetation or canopy characteristics, landscape features and wildland fire behavior, effects and regimes. These products are created at a 30-meter grid resolution and downloadable for all the continental United States. Note that the LANDFIRE dataset was used in place of the individual MRLC Consortium and the USDA/SO-FIA datasets.

Below are Web sites where LANDFIRE information and downloads are located.

- LANDFIRE information Web site: http://www.landfire.gov/ .

- LANDFIRE data download Web site: http://landfire.cr.usgs.gov/viewer/ .

3.b.3. Soil Type/Texture

STATSGO2 data was used. The STATSGO spatial and tabular data were revised and updated in 2006, when it was then named STATSGO2.

The STATSGO2 data was downloaded as a series of ESRI shape files as well as a complex database. To help facilitate analysis of the data, the USDA-NRCS provides a Soil Data Viewer download. The Soil Data Viewer helps process the data within the database. It consists of two major parts:

1. An ESRI ArcMap extension. It allows the user to create thematic soil maps as well as tabular format.
2. A stand-alone program. The program also allows for analysis of the database but output is limited to tabular format.

Below are Web sites where STATSGO2 data as well as the Soil Data Viewer are located.

- STATSGO2 data download Web site (Geospatial Data Gateway): http://datagateway.nrcs.usda.gov/ . Direct URL to STATSGO2 data: http://soildatamart.nrcs.usda.gov/USDGSM.aspx .
- USDA-NRCS Soil Data Viewer Web site: http://soils.usda.gov/sdv/ .

To obtain the soils data, use the direct URL (provided above) to the STATSGO2 data. On the resulting Web page, click on the green button labeled "Start WSS." On the next page, click on the tab titled "Download Soils Data." Then select the option named "U.S. General Soil Map (STATSGO2)." Download the desired zip file.

Note that the USDA-NRCS Soil Data Viewer software is also needed. The URL for the software is provided above. Note that a user with admin privileges will need to install the software on a Windows PC. Also be sure to follow the steps in the instructions to register the software with ArcMap.

Note that per the Soil Data Viewer documentation, one will first have to run some "join" macros in the soils data database before the soils data can be used in ArcMap. The macros should run automatically the first time that the soils data MS Access file is opened. Once the data is joined in the MS Access file, follow the Soil Data Viewer user instructions to open the data in ArcMap.

4. Data Import and Raster Alignment

Geographic Information System (GIS) software ArcMap 10 was utilized to perform all processes required to create the FFPI. In order to perform any analysis on multiple raster layers, the layers must be spatially aligned with respect to one another. This section will describe the process that was undertaken to correctly overlay each raster dataset and prepare them for spatial analysis. Many of the tools used within this project are located in the Spatial Analyst extension of the ArcMap 10 software.

4.a. USGS DEM Data

As notated in the section above, this dataset came in multiple small square tiles that span the entire state of Iowa. Therefore, ArcMap tools need to be utilized in order to stitch these tiles together and prepare them for overlay.

- Mosaic the individual tiles to the geographic region of interest. Navigate to ArcToolbox. In ArcToolbox, navigate to ***Data Management Tools -> Raster*** -> ***Raster Dataset -> Mosaic***.
- The mosaicked rasters should be re-projected. A suggested projection is "USA Contiguous Albers Equal Area USGS." In ArcToolbox, navigate to ***Data Management Tools -> Projections and Transformations*** -> ***Raster -> Project Raster***.
- The dataset comes in meters, but for purposes of the FFPI it needs to be converted to feet. In ArcToolbox, navigate to ***Spatial Analyst*** -> ***Map Algebra***. Input the DEM raster dataset (in meters) and divide by 0.3048 to get feet. (This is the conversion factor to go from meters to feet.)
- (Optional) If desired, clip the mosaicked rasters to a specified geographic area. At WFO Des Moines the rasters were clipped to a geographic area defined by the outline of the State of Iowa plus a 5-mile buffer. In ArcToolbox, navigate to ***Spatial Analyst*** -> ***Extraction -> Extract by Mask***.
- The DEM data needs to be manipulated to come up with a percentage of slope. In ArcToolbox, navigate to ***Spatial Analyst*** -> ***Surface*** -> ***Slope***. Select output measurement to ***percent_rise***.
- (Optional) If desired build pyramids and derive summary statistics for the data. In ArcToolbox, navigate to ***Data Management Tools -> Raster -> Raster Properties -> Build Pyramids and Statistics***.

4.b. STATSGO2 Data

The STATSGO2 dataset is only downloadable in ESRI shapefile, which needs to be converted to a raster GRID file in order to prepare the data for spatial calculations.

- If shapefiles for multiple states were obtained, combine the individual state shapefiles into a single shapefile. In ArcToolbox, navigate to ***Data Management Tools -> General -> Merge***.
- The shapefile should be re-projected. Use the same projection chosen in Section 4.a. In ArcToolbox, navigate to ***Data Management Tools -> Projections and Transformations -> Feature -> Project***.
- (Optional) If desired, clip the shapefile to a specified geographic area. At WFO Des Moines the rasters were clipped to a geographic area defined by the outline of the State of Iowa plus a 10-mile buffer. In ArcToolbox, navigate to ***Analysis Tools -> Extract -> Clip***.
- Convert the shapefile to a raster. In ArcToolbox, navigate to ***Conversion Tools -> To Raster -> Polygon to Raster.*** Set cell assignment to ***cell_center*** and cell size to ***30***.
- The newly created raster now needs to be shifted slightly to perfectly align with the USGS DEM raster. In ArcToolbox, navigate to ***Data Management Tools -> Projections and Transformations -> Raster -> Shift***. Shift X coordinates by **0** and shift Y coordinates by **0.** Set input snap raster to the DEM raster.
- (Optional) If desired, clip the resulting raster to a specified geographic area. At WFO Des Moines the rasters were clipped to a geographic area defined by the outline of the State of Iowa plus a 5-mile buffer. In ArcToolbox, navigate to ***Spatial Analyst*** -> ***Extraction -> Extract by Mask***.

4.c. LANDFIRE Data

Both the LANDFIRE land use and vegetation cover are natively 30-meter rasters. Therefore, all that needs to be done is a simple shift to align this data with the previous rasters.

- When the LANDFIRE data was downloaded at WFO Des Moines, it was natively in the projection "USA Contiguous Albers Equal Area USGS" which was recommended in Section 4.a. If the LANDFIRE data is not in this projection, ensure that it is in the projection chosen in Section 4.a. If it is not, then re-project it. In ArcToolbox, navigate to ***Data Management Tools -> Projections and Transformations*** -> ***Raster -> Project Raster***.
- (Optional) If desired, clip the rasters to a specified geographic area. At WFO Des Moines the rasters were clipped to a geographic area defined by the outline of the State of Iowa plus a 5-mile buffer. In ArcToolbox, navigate to ***Spatial Analyst*** -> ***Extraction -> Extract by Mask***.
- In ArcToolbox, navigate to ***Data Management Tools -> Projections and Transformations -> Raster -> Shift***.
- (Optional) If desired, clip the resulting raster to a specified geographic area. At WFO Des Moines the rasters were clipped to a geographic area defined by the outline of the State of Iowa plus a 5-mile buffer. In ArcToolbox, navigate to ***Spatial Analyst*** ->

Extraction -> Extract by Mask.

5. Raster Reclassification

ArcMap software has the capability to reclassify raster datasets, which simply means assigning a new range of values to the field contained in the raster. Since the main goal of this project is to come up with an indexed value that spans from 1 to 10, each raster dataset will be reclassified to fit this range. The reclassification technique and GIS procedures are described for each dataset in this section.

To reclassify within ArcMap, navigate to the ArcToolbox. Since this raster contains decimal values, the ***Map Algebra*** tool will need to be utilized. In ArcToolbox, navigate to ***Spatial Analyst -> Map Algebra -> Raster Calculator***.

Note: when doing raster reclassification, be sure to select the option to set <no data> values equal to zero.

5.a. USGS DEM Data – Slope

Slope is an important component in flash flooding potential, due to the potential for rapid runoff. Experience suggests that any slope exceeding 30 percent leads to extremely quick runoff and a rapid response in local creeks and streams. Therefore, the formula below was created to reclassify percentage slope into an FFPI value, setting any slope of 30% or higher to an FFPI of 10.

$$Slope\ index = 10^{n/30}$$

Where

n = percent slope $\leq$ 30. If n > 30, then FFPI = 10.

Equation 5. Slope index equation using slope expressed as a percent.

Another method to index the slope is to base the index value on the degrees of slope per the below equation.

$$Slope\ index = 1 + [(\sin\theta) * 9]$$

where

θ = slope in degrees.

Equation 6. Slope index equation using slope expressed in degrees.

5.b. STATSGO2 Data – Soil Type

Sand and clay are very important components of soils when assessing runoff potential. A soil type consisting of 100% sand will lend very little surface runoff, while 100% clay soils will maximize runoff. The STATSGO2 dataset contains percent clay and percent sand for all soils. The soil type raster was reclassified according to the equations below into two new indexed rasters, one for percent clay and one for percent sand. These values were then averaged to come up with an accurate FFPI.

Below are the equations used to determine the soil type index values for both percent clay and for percent sand, as well as the equation to determine the FFPI based on those values.

$$Clay\ soil\ type\ index = 0.5\{\left(1 + \frac{n}{100}\right)(9)\}$$

where

n = percent clay.

Equation 7. Soil type index equation for percent clay.

$$Sand\ soil\ type\ index = 0.5\left\{\left(1 + \frac{(100 - n)}{100}\right)(9)\right\}$$

where

n = percent sand.

Equation 8. Soil type index equation for percent sand.

$$S = 0.5(Clay\ soil\ type\ index + Sand\ soil\ type\ index)$$

Equation 9. Equation to determine soil type contribution to the FFPI based on the Clay and Sand soil type indexes.

5.c. LANDFIRE Data – Vegetation Cover and Land Use

The LANDFIRE dataset includes many different components, including biophysical settings, existing vegetation cover (EVC), existing vegetation height and existing vegetation type. The FFPI uses solely the EVC component because it was overall the most applicable to flash flood threat assessment in Iowa.

EVC essentially combines vegetation cover and land use into one composite dataset. For vegetation cover, each EVC classification has a potential range of 0 to 100% canopy cover. EVC values are binned into discrete classes—up to 10 bins at 10% intervals for tree, shrub and herbaceous canopy cover. Not all EVC classification occurred within Iowa. The EVC data was reclassified into the appropriate FFPI values. The values were subjectively assigned because it would be extremely difficult to scientifically document the contributions of vegetation to water runoff. Some of these values were simply assigned, while tree, shrub and herb cover were given upper and lower bounds, then assigned mathematically.

Table 1 below shows the FFPI values which were assigned to the EVC classifications. Following the table are the equations used to assign FFPI values of tree, shrub and herb cover. The assigned FFPI values were determined using the knowledge and experience of the authors. The following ranges were used for Tree Cover, Shrub Cover and Herb Cover:

- Tree Cover: FFPI ranging from 5.5 (Category #1) to 2.0 (Category #9).
- Shrub Cover: FFPI ranging from 7.0 (Category #1) to 4.0 (Category #9).
- Herb Cover: FFPI ranging from 7.5 (Category #1) to 5.0 (Category #9).

Equation 11, Equation 12 and Equation 13 were constructed using the above ranges. Within each equation, a linear relationship was used between the FFPI value and the LANDFIRE Enumerated Value.

LANDFIRE Enumerated Value	Vegetation Cover	Assigned FFPI Value
11	Open Water	1
13	Developed-Upland Deciduous Forest	3
14	Developed-Upland Evergreen Forest	3
15	Developed-Upland Mixed Forest	3
16	Developed-Upland Herbaceous	5.5
17	Developed-Upland Shrubland	5.5
23	Developed-Medium Intensity	8.5
24	Developed-High Intensity	9.5
25	Developed-Roads	10
31	Barren	8
32	Quarries-Strip Mines-Gravel Pits	2
60	NASS-Orchard	5.5
61	NASS-Vineyard	5.5
63	NASS-Row Crop-Close Grown Cop	5
64	NASS-Row Crop	5
65	NASS-Close Grown Crop	5
66 & 67	NASS-Pasture and Hayland	6
75	Herbaceous-Semi-dry	6
76	Herbaceous-Semi-wet	5
81	Pasture/Hay	6
82	Cultivated Crops	5
83	Small Grains	4.25
84	Fallow	3.5
85	Urban-Recreational Grasses	2.75
95	Herbaceous Wetlands	2
101	Tree Cover>=10 and <=20%	See Equation 11 below
102	Tree Cover>=20 and <=30%	See Equation 11 below
103	Tree Cover>=30 and <=40%	See Equation 11 below
104	Tree Cover>=40 and <=50%	See Equation 11 below
105	Tree Cover>=50 and <=60%	See Equation 11 below
106	Tree Cover>=60 and <=70%	See Equation 11 below
107	Tree Cover>=70 and <=80%	See Equation 11 below
108	Tree Cover>=80 and <=90%	See Equation 11 below
109	Tree Cover>=90 and <=100%	See Equation 11 below
111	Shrub Cover>=10 and <=20%	See Equation 12 below
112	Shrub Cover>=20 and <=30%	See Equation 12 below
113	Shrub Cover>=30 and <=40%	See Equation 12 below
114	Shrub Cover>=40 and <=50%	See Equation 12 below

115	Shrub Cover>=50 and <=60%	See Equation 12 below
116	Shrub Cover>=60 and <=70%	See Equation 12 below
117	Shrub Cover>=70 and <=80%	See Equation 12 below
118	Shrub Cover>=80 and <=90%	See Equation 12 below
119	Shrub Cover>=90 and <=100%	See Equation 12 below
121	Herb Cover>=10 and <=20%	See Equation 13 below
122	Herb Cover>=20 and <=30%	See Equation 13 below
123	Herb Cover>=30 and <=40%	See Equation 13 below
124	Herb Cover>=40 and <=50%	See Equation 13 below
125	Herb Cover>=50 and <=60%	See Equation 13 below
126	Herb Cover>=60 and <=70%	See Equation 13 below
127	Herb Cover>=70 and <=80%	See Equation 13 below
128	Herb Cover>=80 and <=90%	See Equation 13 below
129	Herb Cover>=90 and <=100%	See Equation 13 below

Table 1. FFPI values used for EVC classifications.

FFPI Value =

$$Lowest\ Assigned\ FFPI\ Value + \frac{Max\ LANDFIRE\ \# - x}{Max\ LANDFIRE\ \# - Min\ LANDFIRE\ \#}(\text{Highest Assigned FFPI Value} - \text{Lowest Assigned FFPI Value})$$

Equation 10. General formula for tree, shrub and herb cover.

The below equations are specific to tree, shrub and herb cover. They follow the pattern of Equation 10.

$$FFPI = 2 + \frac{109 - x}{109 - 101}(5.5 - 2)$$

where

x = Tree cover Category number (e.g., 25% tree cover would be LANDFIRE Enumerated Value #102).

Equation 11. Tree cover formula based on Category number.

$$FFPI = 4 + \frac{119 - x}{119 - 111}(7 - 4)$$

Where

x = Shrub cover Category number (e.g., 55% shrub cover would be LANDFIRE Enumerated Value #115).

Equation 12. Shrub cover formula based on Category number.

$$FFPI = 5 + \frac{129 - x}{129 - 121}(7.5 - 5)$$

where

x = Herb cover Category number (e.g., 85% herb cover would be LANDFIRE Enumerated Value #128).

Equation 13. Herb cover formula based on Category number.

6. Results

6.a. Raster Calculations

Once the datasets were reclassified, they were combined using the ArcMap Raster Calculator tool. In ArcToolbox, navigate to ***Spatial Analyst -> Map Algebra -> Raster Calculator.***

The output from Raster Calculator was the FFPI for the entire state of Iowa on a 30-meter grid. This data was quite noisy. To help facilitate better understanding and determination of flash flood risk, the data was consolidated into small sub-basins. The sub-basins chosen were the same ones used the NWS's Flash Flood Monitoring and Prediction (FFMP) software. The data was consolidated using the ArcMap Zonal Statistics tool. In ArcToolbox, navigate to ***Spatial Analyst -> Zonal -> Zonal Statistics.*** The statistic type of MEAN was used. The option to ignore NoData in calculations was turned ***off***.

6.b. FFPI Scenarios

Four different scenarios of the FFPI were calculated for Iowa using different FFPI formulas. Each scenario featured two sub-scenarios. The first sub-scenario expressed slope as a percent. The second sub-scenario (i.e., with an "a" appended to the scenario number) expressed slope in degrees. The ArcGIS ModelBuilder was used to help facilitate the work involving FFPI calculation and data consolidation into FFPI sub-basins.

Table 2 describes each of the four scenarios used. The results of each scenario—including sub-scenarios—are shown in Figure 8, Figure 9, Figure 10 and Figure 11 respectively.

Scenario	Equation Used	Notes
Scenario #1	$FFPI = \dfrac{(M + S + LV)}{3}$	New FFPI formulation
Scenario #2	$FFPI = \dfrac{(M + S + 2(LV))}{4}$	Similar to FFPI formulation from WFO Mt. Holly, NJ
Scenario #3	$FFPI = \dfrac{(1.5(M) + S + 1.5(LV))}{4}$	Similar to FFPI formulation from WFO Binghamton, NY
Scenario #4	$FFPI = \dfrac{(2(M) + S + 2(LV))}{5}$	New FFPI formulation

Table 2. Descriptions of the FFPI scenarios used.

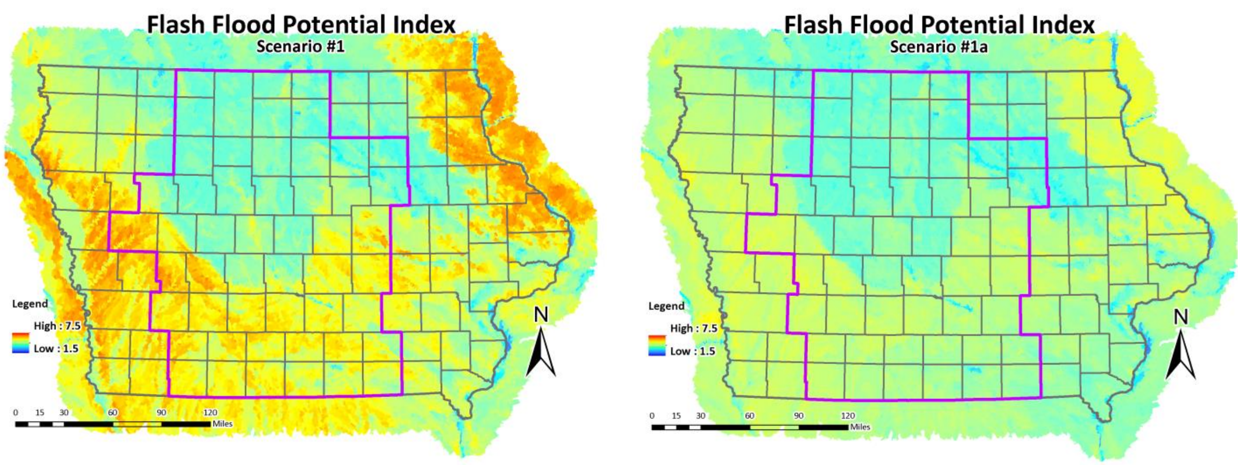


Figure 8. FFPI for Iowa FFMP sub-basins, Scenario #1 and #1a.

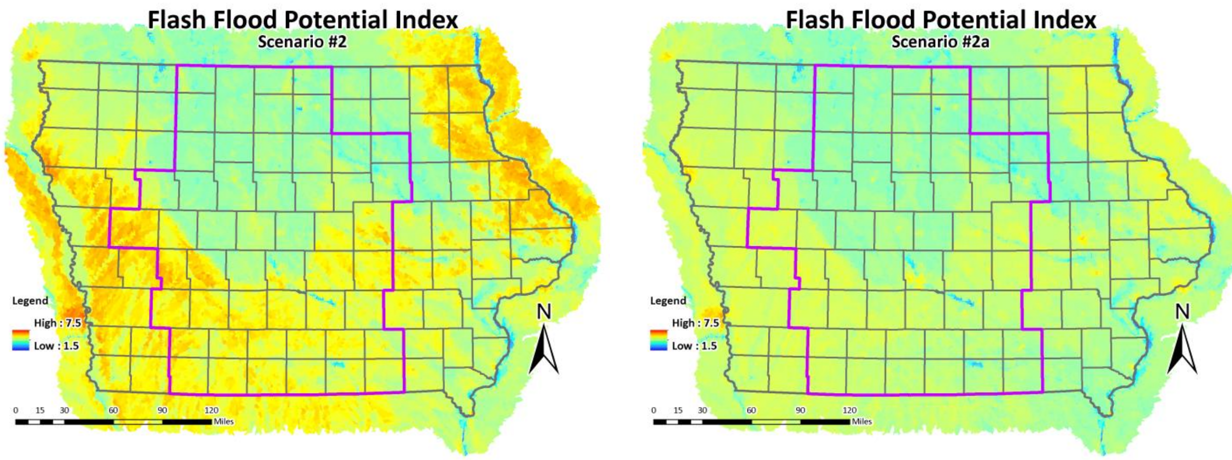


Figure 9. FFPI for Iowa FFMP sub-basins, Scenario #2 and #2a.

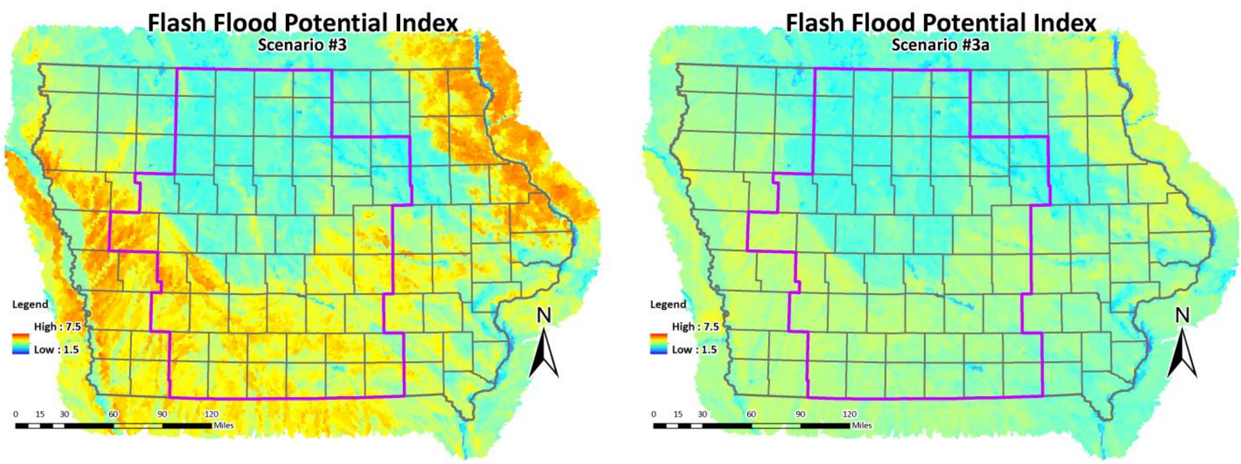
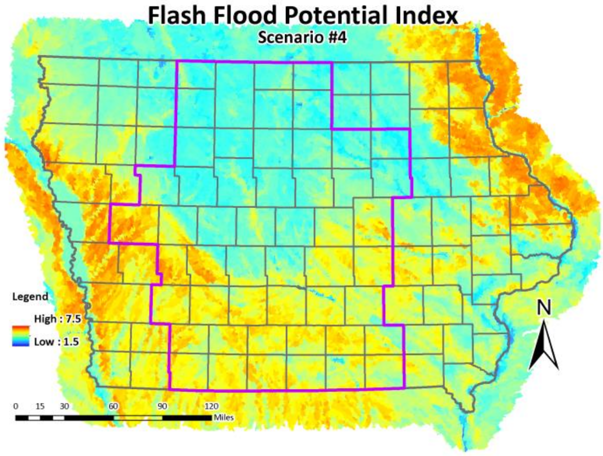


Figure 10. FFPI for Iowa FFMP sub-basins, Scenario #3 and #3a.



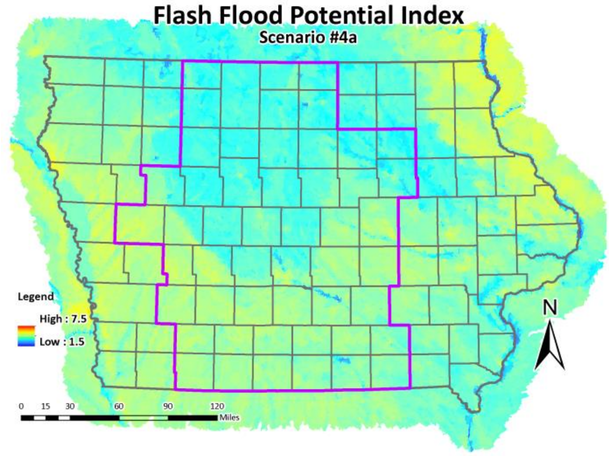


Figure 11. FFPI for Iowa FFMP sub-basins, Scenario #4 and #4a.

6.c. Conclusions

A few conclusions can be drawn from the maps displayed above. First, it is rather evident by comparing a particular scenario to its sub-scenario (i.e., Scenario #1 to Scenario #1a) that using percent slope in the calculation shows more variation in the map than degrees of slope.

Second, Scenarios #3 and #4 showed the greatest variation in FFPI values across the state, with Scenario #1 a close second. Scenario #2 showed the least variation.

Finally, Scenarios #3 and #4 turned out to be rather similar, which is not overly surprising given the same variables (slope and land/vegetation cover) were given extra weighting in the formula. The overall "best" map for Iowa, in terms of which map best depicts actual flood-prone areas across the region, will need to be researched further (see the "Additional Work" section below).

7. FFPI Uses in the WFO Environment

Although the FFPI was originally developed in the RFC environment, it has potential uses at the WFO level. Below is a list of potential uses. The list is not intended to be all-inclusive; other potential uses may exist.

- WFO staff familiarization regarding potential flash flood problem areas within the WFO's County Warning Area.
- A supplement to FFMP to help identify areas that may be predisposed to flash flooding.

In addition, the FFPI may help make a forecaster make the flash flood warning decision if that forecaster is "on the fence" regarding their decision to warn.

- Information to be shared with NWS partners to help elevate their situational awareness regarding flash flood potential.

Again, as stated in Section 1.c. , the FFPI is only a tool. The FFPI should be used in concert with other flash flood tools to help the NWS provide the best possible flash flood warning services.

8. Additional Work

The FFPI has proven to be a useful tool across other areas of the country. To assess its utility in the state of Iowa, however, correlation studies between the FFPI and actual flash flood occurrences should be performed. A study of this sort may also lead to a better understanding of what weighting functions (i.e., the scenarios above) in the FFPI highlight the more favorable locations of flash flooding.

While the FFPI is a potentially useful tool in its current form, the FFPI does not take current soil moisture conditions into account, which is known to be a large factor in rainfall runoff amounts. Future work could involve combining antecedent moisture conditions, the FFPI, and real-time rainfall data into one powerful tool that could be used by NWS forecasters in flash flood warning operations.

9. References

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(End)